University of Moratuwa

Faculty of Engineering

Department of Electronic & Telecommunication Engineering

EN1053 Introduction to Telecommunications

B.Sc. Eng., Semester 2 **2015 Batch**

Build, test and make measurements of a Yagi–Uda Antenna Array

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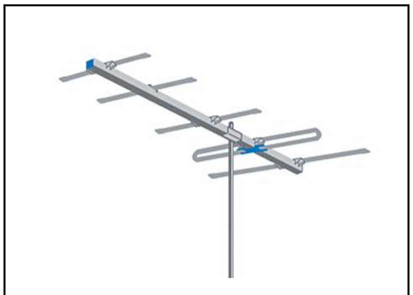
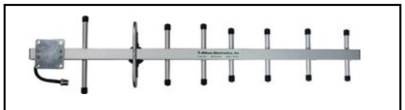
1. Introduction

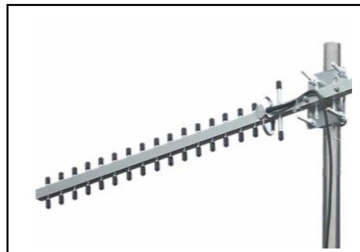
Yagi-Uda antenna is used in the VHF and UHF ranges and it is simply known as the Yagi antenna. It is commonly used to receive TV signals. It is also used as an outdoor antenna in cellular communications and as a Wifi antenna. Fig.1 shows a few such antennas.



(a) Yagi VHF TV antenna



(b) Out-door Yagi cellular antenna for 800 MHz with 13 dB gain



(c) Wifi Yagi antenna for 2.4 GHz with 18 dBi gain

Fig. 1 Yagi-Uda antenna array (a) for TV reception, (b) Cellular communication and (c) Wifi networks

It is an antenna with one driven element and several passive elements. The driven element is energized directly by a feed transmission line while the others act as parasitic radiators whose currents are induced by mutual coupling. See Fig.2.

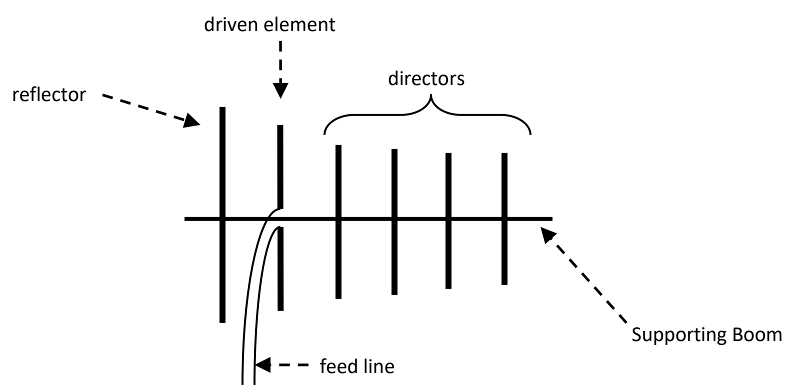
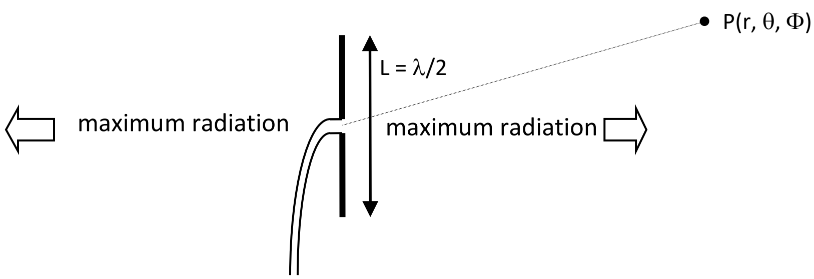


Fig. 2 – Elements of a Yagi-Uda antenna array

The driven element is ‘resonant’ and it is slightly shorter than $\lambda/2$ so that its impedance is entirely resistive. It is a HW dipole but slightly shorter so that it is resonant.
There are several directors and they are shorter than the driven element; they are capacitive.
The reflector is longer than the driven element; normally there is only one and it is inductive.

2. Properties of a Half Wave Dipole

The maximum radiation from a vertical HW dipole is horizontal as shown in Fig.3.
The expression for the electric field in the far field is given in equation (1).



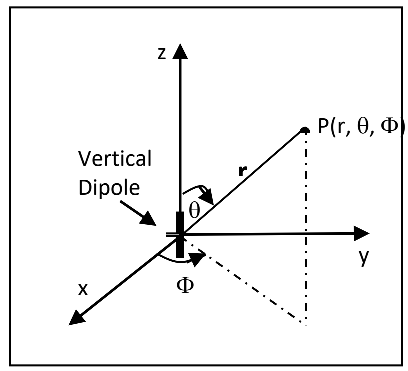


Fig. 3 – A vertical HW dipole

Far field electric field at point P(r, θ, Φ) is given by, $E(\theta) = E_0 \cdot \left| \dfrac{Cos\ [(\frac{\pi}{2})\cos(\theta)]}{Sin(\theta)} \right|$ …………(1)

Hence the horizontal plane radiation pattern which is a polar plot of $|E(\theta)|$ vs θ as shown in Fig.4.

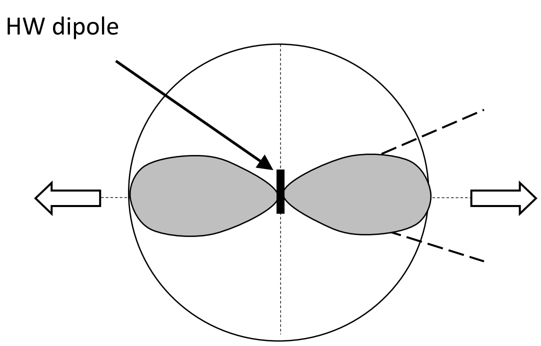


Fig.4 Radiation Pattern of a vertical HW dipole in the vertical plane

Important parameters of a vertical HW dipole

- Half power beam width = 78°
- Directivity = 1.64 [= 2.15 dB]
- Gain = 2.15 dB
- Z_{in} = 73 + j 42.5 Ω
- R_a - Radiation resistance = 73 Ω
- Polarization: vertical

3. Half Wave Dipole with parasitic elements

We can improve the antenna gain of the HW dipole by adding parasitic elements. It can allow the maximum radiation to be directed more in one direction unlike in the HW dipole with no parasitics.

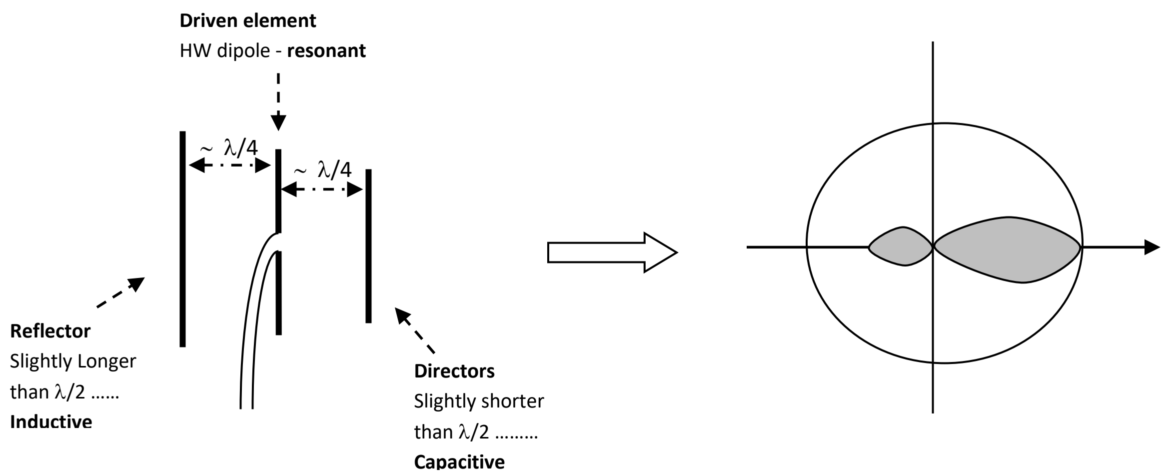


Fig**. 5 – HW Dipole with 2 parasitics and its radiation pattern**

Due to mutual effects between the current in the driven element and the parasitics, the radiated field gets modified. As a result, the radiation pattern of the HW dipole with parasitics has major radiation in the direction of the shorter parasitic element. Hence the shorter parasitic element is called a director. The longer element is called the reflector as it helps to reduce the radiation in that direction. This antenna array arrangement gives better directivity.

By increasing the number of directors, the directivity can be further improved.

However, the presence of the parasitic elements reduces the input impedance of the driven element of the array. This causes mismatch problems when a 75 Ω coaxial transmission line is used to feed the HW dipole which has an input impedance of (73 + j 42.5) Ω. A slightly shorter HW dipole has an input impedance close to 73 Ω with no imaginary part and therefore it is resonant.

On the other hand, if the HW dipole is folded, its input impedance gets increased. In the presence of parasitics the input impedance of the folded HW dipole gets significantly reduced.

4. Folded HW Dipole

The common driven element used is a folded HW dipole fed by a transmission line.
The input impedance of the folded HW dipole, Fig. 6, is given by,

$$(Z_{in})folded\ HW\ dipole = 4\ (Z_{in}\ )HW\ dipole$$

$$\sim(4\ x\ 73)\ \Omega\ \ if\ HW\ dipole\ is\ made\ \boldsymbol{resonant}$$

$$\sim 292\ \ \Omega\ \ \ \sim 300\ \Omega$$

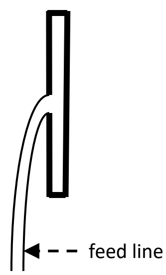


Fig. 6 - Folded HW dipole

The folded HW dipole can therefore be directly fed by a 300 Ω two-wire transmission line.

However, the folded dipole with parasitics has an input impedance much smaller and therefore the Yagi antenna array may be directly fed by a 75 Ω coaxial transmission line with some impedance mismatch.

5. Yagi Antenna design

Therefore the Yagi antenna includes a folded HW dipole slightly shorter than λ/2 to make it resonant which is the driven element ; a few directors slightly shorter than the driven element ; and a reflector which is slightly longer than the driven element. You can include 3 or 4 directors.

Build the Yagi antenna according to the guidelines provided in Fig.7

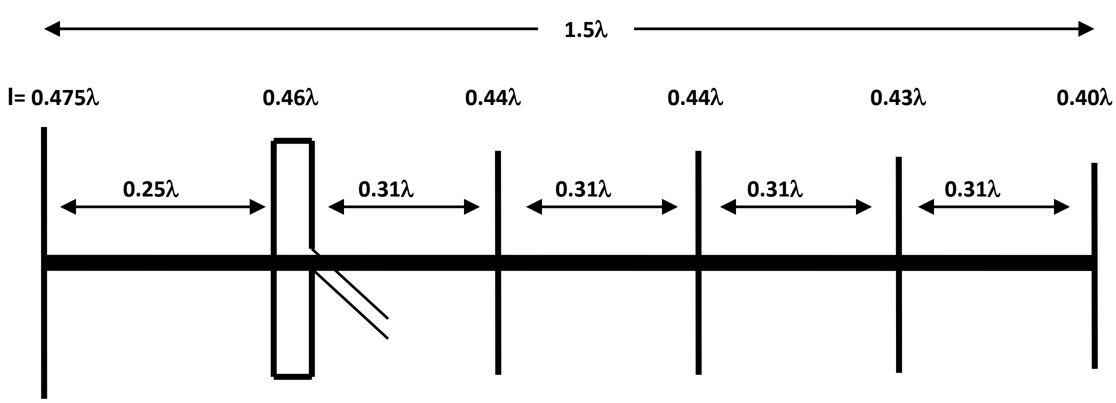


Fig.7: A 6 element Yagi antenna array

6. Antenna Radiation Pattern Measurements

- Fix the antenna with the feed line, on to a rotatable stool so that the antenna can be rotated through 360°. This is the Antenna Under Test (AUT).
- Connect the antenna coaxial feed line to a spectrum analyzer. The AUT is the receive antenna for radiation pattern measurements. The transmitter is the appropriate TV transmitter which is far away. The signal received by the AUT from the TV transmitter is measured using the spectrum analyzer. The set up is shown in Fig.8 and a typical display on the spectrum analyzer is shown in Fig. 9.

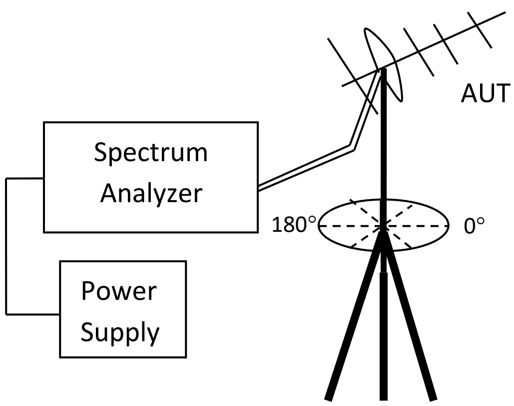


Fig.8 - Measurement set

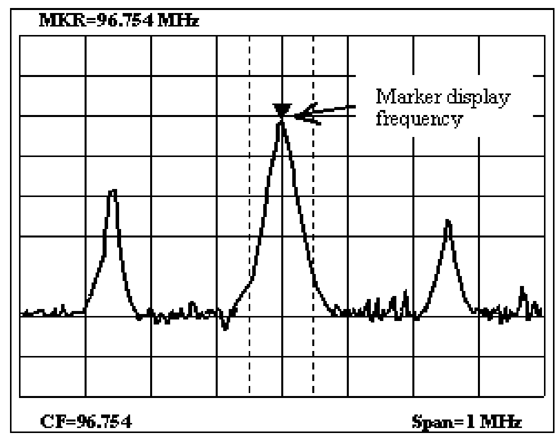


Fig. 9 – Spectrum analyzer

- Turn the AUT towards the appropriate TV transmitter until the maximum received field strength is observed on the spectrum analyzer for the frequency of the AUT.
- Turn the circular degree scale of the antenna set up, towards the direction of the antenna such that the scale reads 0° for the direction of the maximum received signal.
- Record the maximum spectrum analyzer reading corresponding to the angle $\theta = 0°$.
- Turn the antenna through 10° or 15° steps and record the received signal strength from the spectrum analyzer through 360°.
- Draw a polar plot of the received signal strength from the spectrum analyzer as a function of $\theta°$.
- This is the radiation pattern of the AUT.

7. Antenna Gain Measurement

Antenna Gain is define by equation (2),

$$Gain\ w.r.t.\ an\ isotropic\ radiator, G_0 = \frac{E_{max}}{E_{av}} \quad \text{.......................................(2)}$$

However, gain is usually expressed w.r.t. a HW dipole and it is defined by equation (3).

$$Gain\ w.r.t.a\ HW\ dipole, G_{HW} = \frac{E_{max}}{(E_{\max})_{HW}} \text{ ……………………………………(3)}$$

Hence we need to obtain E_{max} due to a HW dipole to obtain G_{HW}.

- Therefore measure the maximum received signal using a HW dipole antenna as the receive antenna, for the same transmitter by replacing the AUT with a HW dipole antenna designed for the same frequency.
- Record the maximum spectrum analyzer reading = $(E_{max})_{HW}$
- Hence calculate the gain of the test antenna in dB.
- When the gain is measured w.r.t to a HW dipole, the gain is expressed as dBd. The last letter 'd' in dBd stands for dipole and that the gain is referred to a HW dipole.
- If the gain is estimated w.r.t. a isotropic radiator it is expressed as dBi; the last letter 'i' meaning isotropic.